Comprehensive Assessment of Environmental, Economic, and Social Impacts in Rice Cultivation: A Life-Cycle Analysis

Saira Muneer
Lahore College for Women University Lahore
***Correspondence**: sairamuneer69v@gmail.com

Citation | Muneer. S, "Comprehensive Assessment of Environmental, Economic, and Social Impacts in Rice Cultivation: A Life-Cycle Perspective Life Cycle Analysis", IJASD, Vol. 5 Issue. 2 pp 52-66, May 2023
Received | April 07, 2023, **Revised |** April 19, 2023, **Accepted |** May 03, 2023, **Published |** May 15, 2023.

Since rice is the cereal that people eat most of all over the world, producing it is crucial for feeding everyone on the planet. Therefore, considering its importance in terms of nutrition and economics, evaluating the sustainability of this production method is essential. This comprehensive review investigates the life cycle environmental impacts, economic considerations, and social aspects associated with global rice cultivation. Spanning diverse regions, the study employs a comparative analysis using Global Warming Potential (GWP) as a benchmark, revealing variations in greenhouse gas emissions per metric tonne of rice. Malaysia and Italy, employing distinct cultivation techniques, exhibit similar results, highlighting the nuanced environmental impacts influenced by climate and soil conditions. Sensitivity analysis evaluation underscores its significance in understanding the impact of different assumptions on study outcomes, while life cycle costing is explored, revealing a tendency to overlook economic aspects in rice industry Life Cycle Analysis (LCA) investigations. Social Life Cycle Analysis (S-LCA) introduces socio-economic considerations, unveiling potential risks associated with child labor, forced labor, fair wages, and working conditions in the global rice industry. Key discoveries indicate India consistently exhibits the highest medium-high social risks, emphasizing the potential widespread impact of social issues in the global rice trade. The study concludes by emphasizing the need for additional research into the societal impacts of rice agriculture, serving as a valuable starting point for promoting sustainable and socially responsible practices in the global rice industry. Recommendations include employing diverse operational entities, aligning methodologies, addressing regional priorities, and conducting comprehensive LCAs by leading rice-producing countries.

Keywords: Nutrition and Economics, Climate and Soil Conditions, Fair Wages, Global Rice Trade, Social Risks.

Introduction:

With ongoing economic development and population growth, global energy consumption, especially in agriculture, is increasing annually. Achieving a more secure and sustainable energy future requires a focus on energy efficiency. Stabilizing energy supply is crucial for enhancing energy security on a national level. The increasing global demand for energy and trade has underscored the importance of energy diversification, generation, and efficient allocation. Therefore, analyzing energy use becomes a vital step in formulating effective energy policies. Developing agricultural systems with low energy inputs not only contributes to emission reduction but also enhances food production security [1].

Governments and non-governmental organizations recognize the importance of motivating farmers to adopt resource-conserving practices on their own farms. This requires investment in participatory processes to bring people together, identify common problems, and form groups or associations capable of developing practices for mutual benefit. Collective management programs have experienced significant growth globally in recent years. Social capital, representing aspects of social structure that serve as resources for individuals and facilitate cooperation, plays a crucial role in this context. Effective norms serve as a powerful form of social capital, and various perspectives explain how social capital groups form and feature within a population. Local groups addressing watershed/catchment management, irrigation management, micro-finance delivery, forest management, integrated pest management, and farmers' research groups have emerged in developing countries. The formation of social capital groups for water users has led to higher rice yields in certain regions through efficient water consumption [2].

However, in Iran, the emergence of such social capital associations at the local level has not reached a significant level. Efforts are needed to encourage the formation of social capital at the village level. It is evident that new thinking and farming practices are necessary, particularly to develop social and governmental organizations structurally suited for both farms and natural resource management at the local level. Energy is utilized in Iranian agriculture in various forms, from diesel fuel and fertilizer consumption to different types of farm machines. Notably, energy indices alone cannot fully represent all environmental impacts. Other impacts, such as acidification and global warming potential, should also be considered. Additionally, a comprehensive LCA is essential, as it assesses the environmental impact of a product throughout its production stages, from cradle to grave. The ISO 14040 standard outlines four main phases of an LCA procedure: goal and scope definition, inventory analysis, impact assessment, and interpretation [3].

LCA is a systematic approach used to evaluate a system or product, enabling the measurement of its potential environmental impacts and the analysis of tradeoffs among various environmental effects. Standardized by the International Organization for Standardization (ISO) through ISO 14040:2006 and ISO 14044:2006, LCA comprises four standardized steps—Goal and scope definition, inventory, impact assessment, and interpretation of results—aiming to align its application across practitioners. The initial phase, Goal, and Scope Definition are crucial as they establish the approach and guide decisions about the product system under consideration [4].

The Life Cycle Inventory phase involves tracking all material inputs and outputs in a production system, including raw materials, water, energy, and emissions into the environment. LCI analysis can be complex, covering multiple supply chains and numerous tracked substances. The Life Cycle Impact Assessment evaluates environmental impacts based on data collected in the inventory analysis. Lastly, the Interpretation phase involves analyzing and identifying improvement opportunities, along with checks for completeness, sensitivity, and consistency. Originally used for analyzing industrial products or production systems, LCA has expanded to assess the environmental impacts of the agricultural sector. However, the agricultural context introduces complexities such as multiple products from a single system, regional and crop-specific management techniques, temporal and spatial variations, and a lack of standard approaches for significant consequences like land use and water usage [5].

The United Nations has recently released estimates indicating that the global population currently stands at eight billion people. Projections anticipate a substantial increase, reaching around 11 billion people by the year 2100. This demographic expansion, while marking a notable milestone in human evolution, brings with it the challenge of meeting the growing demand for food. It is anticipated that food intake may need to increase by approximately 40% to sustain the rising population through intensive resource utilization. This underscores the urgency for innovative and sustainable approaches to food production and resource management to ensure global food security in the face of a rapidly growing population [6] [7].

Review Methodology:

The literature review methodology involved exploring the "Scopus" and "Web of Science" databases to retrieve scientific manuscripts published from February 1, 2005, to October 31, 2022. The selection of manuscripts followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, with details outlined in Figure 1. The search queries included the keywords "LCA," "Rice," "Life Cycle Analysis," "Cereals," and "Environmental Impact." Only journal articles published in English were considered during the search process. The initial search yielded a total of 400 articles, which were subsequently reduced to 250 after removing duplicates [8].

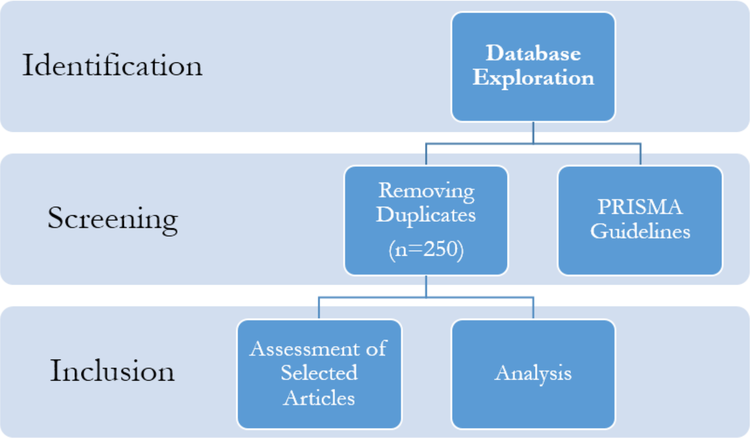

Figure 1: Flow Diagram illustrating Article Selection

A meticulous selection process was undertaken, resulting in the exclusion of 150 studies after a comprehensive title analysis, aligning with the primary objective of this study to review the application of LCA in the rice cultivation sector. The criteria for selection were as follows: only studies published in peer-reviewed journals were included, while conference proceedings, book chapters, Ph.D. and Master's. Additionally, selected studies were required to clearly state and explain the applied methodology, conducting an assessment of environmental performance using the LCA approach. Exclusion criteria encompassed studies not specifically focusing on crop cultivation, such as those centered on the management or re-use/re-purposing of rice or any byproduct. Furthermore, the selected studies needed to evaluate at least one environmental effect or social aspect, thereby excluding articles solely focused on building inventory. These stringent criteria were diligently applied to ensure that the chosen studies contribute directly to the examination of LCA applications in the rice cultivation sector, maintaining a focused exploration of environmental and social impact assessments within this specific context.

Findings and Conversations:

Of the total 150 publications, 72 focused on LCA, while the remaining three centered on Social Life Cycle Analysis. A detailed examination of this research. Analyzing the first 72 articles revealed that China and Iran were the most prolific contributors, with 10 and 12 publications, respectively. Senegal, Spain, and Sri Lanka each made singular contributions, while Malaysia, Brazil, Japan, India, and China each added two publications. Bangladesh, Thailand, and Italy were notable contributors, each submitting three items.

Understanding the geographical distribution of research is paramount due to variations in agricultural practices among nations, driven by factors such as diverse growing seasons, water availability, and input utilization. Consequently, authors tailor their goals according to the customary farming methods prevalent in their respective countries. However, it is noteworthy that only a limited number of studies delve into this aspect [9]

Explicit comparisons between conventional and organic farming practices have been limited within the scope of LCA. This limitation highlights the inadequacy of LCA in accurately differentiating between the two approaches and consequently assessing the advantages and disadvantages associated with organic farming. Notably, research conducted in the Asian belt, encompassing countries such as China, Bangladesh, Malaysia, Thailand, and Japan, omits the use of artificial water as an input. The absence of artificial water input in this region does not directly impact the study outcomes, given the favorable weather conditions experienced by these nations. Studies in this context often concentrate on the management of fertilizers and herbicides. Three studies specifically explore the targeted objective of reducing fertilizer loading in rice and aquaculture.

Functional units employed in these studies vary, with the most frequently used being one kilogram of rice (in 14 research studies), one hectare of land (in 16 studies), and one tonne of rice (in 25 studies). It is noteworthy that several authors have utilized multiple acronyms, including hectare and 1,000 RMB yuan, reflecting the diverse approaches and units of measurement employed in the evaluation of the environmental and socioeconomic aspects of rice cultivation [10], as well as RMB yuan and Nutrition Density Unit [11].

One hectare and one metric tonne or one metric tonne and one Chinese yuan. Extra functional units were selected, like 1 kilogram of protein or 6.8 tonnes of rice [12]. It is evident that there is a preference for researching the cultivation of one hectare of land and the production of one metric tonne of commodities, with less emphasis on other functional units related to nutritional or economic considerations. To ensure a comprehensive understanding of agricultural production sustainability, defining functional units that adequately capture a wide range of aspects is desirable. The use of multiple functional units can effectively communicate the concept of agricultural multifunctionality, making it a fruitful area of research for the application of LCA not only in the rice sector but also in agriculture overall.

Employing 1 kg or 1 ton as a functional unit, and, in a relevant context, 1 acre, can provide insights into the environmental consequences associated with both the primary objectives of production and land use. This mirrors how a profit unit or a nutritional unit can demonstrate the financial and food-related roles of agricultural systems. Given the diverse tasks performed by agricultural systems, it is crucial to assess their effects using functional units that accurately reflect the services these systems offer. However, this review highlights that multifunctionality is seldom considered in LCA research, possibly posing a methodological challenge. To precisely quantify additional externalities and thoroughly explore agricultural multifunctionality, incorporating new functions into evaluation studies is vital.

Limitations of the Framework:

Specifically, the "cradle-to-farm" manufacturing approach is commonly favored in the literature. However, it is noteworthy that writers often use general language without explicitly indicating whether they consider the entire creation process of inputs or solely their consumption. There exists disagreement among professionals regarding the precise definitions of steps, materials, and production processes, highlighting the significant variability in these areas. The literature sporadically references the manufacturing procedures associated with various inputs, including seeds, fertilizers, and pesticides. This variation in approach and terminology underscores the need for a more standardized and explicit delineation of boundaries and considerations within the Life Cycle Analysis framework, particularly concerning the production stages of agricultural inputs [13]. Nevertheless, some authors neglect to consider seed production in their arguments. The conventional practice in LCA research on rice production is to adopt the cradle-to-gate timeframe as the reference boundary. This choice is driven by the fact that studies often concentrate on distinct stages of the production process, and comprehensive data is lacking. The inclusion of variables such as packaging and machinery in current trials introduces complexities that impede direct comparability of results. The transportation of goods to the farm is one such factor that requires careful consideration within the defined reference boundary to ensure a comprehensive and accurate assessment of the environmental impacts associated with rice production

The consensus in LCA research on rice production primarily favors concluding the analysis at the paddy harvesting stage, with occasional consideration given to storage warehouses and machinery production processes. While this aligns with a standardized boundary selection, there are instances where authors extend their focus to additional production processes, including elements like machinery, without clearly outlining the criteria for their inclusion. This variability in approach raises concerns about the comparability of results, as there is a risk of overestimation or underestimation, rendering the outcomes essentially incomparable. Further disparities may arise from authors incorporating different elements, such as consumption or complete manufacturing processes. Additionally, the ambiguity in the descriptions provided by authors contributes to the difficulty of comparing results across various studies in the field of rice production LCA.

Life Cycle Impact Assessment:

From a review encompassing 32% of the evaluated publications, it is apparent that the ReCiPe 2016 MidPoint technique stands out as the most widely employed approach for Life Cycle Impact Assessment (LCIA). ReCiPe represents an updated version integrating elements from the CML-IA baseline, ILCD 2011 Midpoint+, and IMPACT 2002+. Notably, it features fifteen impact categories, differing from the ILCD 2011 Midpoint+ with sixteen categories and the CML-IA baseline with eleven categories. The comprehensive nature of ReCiPe, boasting 18 effect categories and 3 damage categories, suggests that this methodology may offer a more thorough and nuanced evaluation compared to other approaches in the field of LCIA [14]. Due to these considerations, the selection of different Life Cycle Impact Assessment (LCIA) calculation approaches is influenced by various factors, including the characteristics of the study, its objectives, the specific consequences under examination, alignment with the needs of a particular nation, the nationality of the authors, and the desired accuracy of the results. Notably, three frequently employed examples of hybrid techniques in LCIA are the IPCC, Eco points, and Cumulative Energy Demand. These approaches offer flexibility and adaptability to diverse study contexts and objectives, reflecting the nuanced nature of Life Cycle Analysis and the need for tailored methodologies based on specific considerations [15].

Combining various methods in Life Cycle Analysis studies can introduce complexity, making it challenging to analyze and compare results. The technique employed by researchers often determines the specific effect categories they focus on, resulting in occasional disparities in vocabulary even when communicating similar concepts. To mitigate this, the effect category names in this study were represented using common terms and standardized. The impact categories were then categorized based on their frequency of use across the examined literature, revealing a total of thirty-one impact categories across all 37 research studies. These categories were further classified into three primary areas: the environment, human health, and resources, enhancing clarity.

In the environmental category, Global Warming Potential (GWP) attracted the most attention, appearing in 32 studies, followed by Terrestrial Acidification with 27 instances. Freshwater Ecotoxicity was investigated in 16 cases, Eutrophication Potential in 15 cases, and Water Consumption in 13 cases. The emphasis on GWP reflects rice growers' commitment to reducing field emissions and methanogens through ecologically friendly agronomic practices. Additionally, attention to Freshwater Ecotoxicity addresses concerns about pollutants that can threaten food security by infecting aquatic animals, potentially reaching humans through consumption. Eutrophication research underscores the environmental impact of fertilizers containing phosphate or nitrogen, affecting water ecosystems and aquatic life. These findings highlight a dual concern for maintaining ecosystem quality and ensuring food security.

Lastly, the data reveal a notable discrepancy in the attention given to land-use categories, despite rice accounting for 11% of global agricultural land. Only 16 impacts were allocated to land-use categories, suggesting a need for greater emphasis on this aspect in future LCA studies[16]. This highlights a noteworthy gap in research on rice farming, as it does not seem to adequately address concerns related to the loss of natural habitat and land reduction. Nevertheless, the overarching objective remains to enhance rice yield on existing acreage through the optimization of water, energy, and other resources. This suggests a need for a more comprehensive examination of the environmental impacts associated with land use in rice cultivation, especially as global concerns regarding habitat loss and land scarcity continue to grow. Addressing these aspects is crucial for developing sustainable practices that balance increased crop productivity with environmental conservation [17].

Human Welfare:

Human toxicity emerged as the impact category with the highest weight, comprising 23 instances. Additionally, there were impacts on ozone, encompassing particulate matter formation (N = 7), ionizing radiation (N = 5), depletion (N = 14), and formation (N = 4). Compounds with the potential to harm humans, such as heavy metals found in pesticides, typically garnered increased attention due to their emissions. This signifies extensive efforts to regulate these inputs within the rice industry.

The excessive ozone production in the atmosphere, primarily caused by the burning of fossil fuels, underscores its detrimental effects on human health, particularly respiratory issues, and terrestrial ecosystems by reducing plant biomass. Regarding particulate matter formation, various field activities, including agricultural processing, combustion plants, insecticides, and exhaust from farm machinery, can be associated with sources of air pollution. These findings illustrate the comprehensive exploration of diverse environmental impacts associated with rice cultivation, reflecting a commitment to understanding and mitigating potential risks to both human health and the broader ecosystem [17].

The popularity of this category indicates a growing awareness of sustainability issues, emphasizing the desire to safeguard soil and water resources. The study focusing on ionizing radiation delves into the impacts of various energy sources, encompassing industries like nuclear power generation. Conclusions from this study vary depending on the energy mix of each country. However, the choice of impact type should not be solely based on personal preference. Instead, it should be grounded in the fact that several researchers have adopted a specific methodology that incorporates that category, yielding a distinct set of outcomes.

The abundance of an effect category in a method may be attributed to its frequent application. Concerns primarily revolve around the effects of chemical nitrogen fertilizers, encompassing both direct emissions and emissions originating from their manufacturing processes. Additional worries stem from direct CH_4 emissions related to methanogens, as well as consequences of the mechanization phase, such as the production and utilization of diesel and electricity management. These considerations highlight the multifaceted nature of environmental impacts associated with agricultural practices, urging a comprehensive approach to address various contributors to environmental concerns

Resources:

In the macro area of resources, Mineral Resource Scarcity (N = 2) received the least attention, while Fossil Resource Scarcity (N = 13), Metal Depletion (N = 9), and Abiotic Depletion (N = 4) were the most extensively studied effect categories. It's noteworthy, however, that despite having various names, these groupings essentially convey the same concept. The literature assessment reveals a lack of emphasis on the environmental impacts of abiotic resources, with authors showing minimal interest in preventing their depletion.

Overall, there appears to be a deficiency in understanding the quantification of the reduction of non-living resources in LCAs. The concept of abiotic depletion is briefly mentioned in current LCA models, suggesting that it is not considered a significant concern. Nevertheless, the imminent depletion of resources, particularly in light of the recent energy crisis stemming from the conflict between Russia and Ukraine, underscores the need for further investigation.

The exhaustion of abiotic resources may lead to significant consequences, such as increased expenses for energy, raw materials, and semi-finished goods. Agriculture, in particular, may experience immediate effects from these price increases, potentially creating a detrimental feedback loop that poses a threat to ecosystems and the overall national economy.

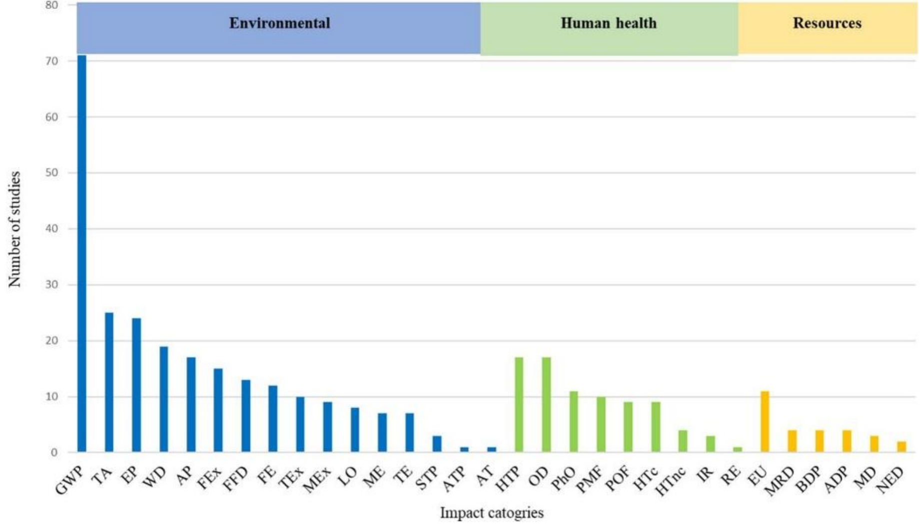

Figure 2: Impact categories examined in the LCA studies [18].

Explanation:

As the literature studies spanned multiple regions (Asia, Europe, Africa, and South America), the findings were extrapolated for the purpose of comparative analysis. GWP, expressed in kilograms of carbon dioxide equivalent (kg CO_2 eq), was selected as the benchmark value in most studies. To ensure comparability across different GWPs, they were standardized to one metric tonne of product, despite occasional variations in functional units among different research. When the functional unit was 1 kg, the GWP was multiplied by a factor of 1000. Results were accurately represented when the functional unit was 1 hectare, and the yield per nation was estimated. This standardization allowed for meaningful comparisons and interpretations across diverse studies conducted in various geographical regions [19]. The calculation of GWP involved multiplying the protein content in one kilogram of rice by 1000, setting the functional unit as 1 kilogram of protein. However, three research studies were excluded from consideration due to discrepancies in the reported percentages. In the context of Iran, the greenhouse gas emissions per metric tonne of rice were estimated to be approximately 298 kg CO_2 equivalent [20]. In Brazil, the greenhouse gas emissions per metric tonne of rice are approximately 482 kg CO_2 equivalent. Italy, on the other hand, has a greenhouse gas footprint of around 1301 kg CO_2 equivalent per tonne of rice [21]. Lastly, Malaysia exhibits emissions of approximately 1390 kg CO_2 equivalent per metric tonne of rice. Notably, Malaysia and Italy achieve roughly similar results despite employing different cultivation techniques. Malaysia relies primarily on rainfall during the monsoon season [22] and a vast canal network, while Italy's production system is irrigated, requiring electricity to operate pumps, leading to associated repercussions. Given that a significant portion of Malaysia's population heavily relies on rice as their main food source, the country's increased use of fertilizers and pesticides may contribute to similar results.

In contrast, countries like China and Japan, which receive abundant rainfall annually, have a plentiful water resource that adequately meets their rice cultivation requirements. Consequently, the consequences of water pumping are disregarded, and the significant environmental impacts (reaching a maximum of 3000 kg CO_2 per tonne for China and 2160 kg CO_2 equivalent for Japan) can mainly be attributed to the widespread utilization of fertilizers, with inconsistent results arising from different boundaries and factors considered. The environmental suitability of rice farming may vary depending on the soil and climate conditions in different countries, influencing the choice of inputs.

In Italy, the predominant cause of the consequences was excessive water usage, directly impacting methanogens and indirectly affecting the power generation required for water pumping. The climatic and soil conditions of Italy are not conducive to the type of horticulture commonly seen in Asia, where regular rainfall ensures a consistent water supply. Instead, Italy requires a continuous artificial water supply to sustain its horticultural activities.

The predominant impacts in Asian nations were linked to the extensive use of pesticides and fertilizers, which has expanded gradually due to advantageous policies and affordability. While pesticides and fertilizers are commonly used in rice-producing countries worldwide, their usage in Europe is regulated by Council Directive 91/676/EEC [23], establishing maximum allowable nitrogen loads per hectare. Diverse outcomes may arise from varying system boundaries, phases, input quantities, and methodological structures, as each author examines a distinct technique. It is crucial to interpret every result within the specific methodology and technique employed, posing a challenge in comparing the studies.

Sensitivity Analysis (SA) Evaluation:

To assess the impact of different assumptions on study outcomes and understand how they change with updated model assumptions, a sensitivity analysis was conducted, incorporating alternative assumptions distinct from those used in the primary analysis [24].

Life Cycle Costing:

Life cycle costing entails the economic assessment of all anticipated and agreed-upon significant cost streams throughout an analysis, expressed in monetary terms. It is recognized as the second pillar of life cycle thinking, as outlined by ISO 15686-5. This methodology unveils the real costs of production before the output is generated. Among the publications scrutinized between 2012 and 2022, a total of five authors (constituting 12% of the sample) incorporated an economic evaluation alongside their analysis [25]. The literature review highlights a common tendency among authors to overlook the economic aspect of LCA investigations. This trend mirrors the broader pattern observed in LCA studies on agri-food products. Authors may have encountered challenges in adapting the life cycle cost analysis to the specific processes under consideration [26]. Nevertheless, it is important to highlight that economic data for inputs are often well-established and readily calculable, which should make their identification less challenging. Consequently, it appears that the aspect of economic sustainability in the rice industry has been neglected. This oversight could also limit the utilization and application of other analytical tools, such as the Eco-Care Matrix [27].

Assessment of the Social Life Cycle:

The third component of sustainability analysis, referred to as S-LCA, evaluates the socio-economic impact of various stakeholders, encompassing both positive and negative aspects, throughout the entire lifespan of the product [28]. [29] specifically concentrated on rice farming in China, examining the social aspects. The other two studies, conducted in Thailand, compared various crops. This limited focus on social aspects within the literature highlights the need for more comprehensive research on the social dimensions of rice farming, particularly in diverse geographical and cultural contexts. Due to the absence of a standardized method for Social Life Cycle Analysis (S-LCA) or a reference standard for Social Life Cycle Impact Assessment (S-LCIA, ISO/AWI 14075 under development), each author employed a distinct methodological framework to analyze social impacts. These frameworks included the calculation of normalized percentages or the use of semi-qualitative social indicators. Despite the UNEP recommendations being available for over a decade, the inaugural S-LCA study in the rice sector was only concluded in 2019. S-LCA is underutilized in rice production, attributed to methodological challenges, such as unreliable data and databases, difficulty in determining system boundaries, cut-off criteria, and functional units, as well as the lack of agreed-upon standards for selecting stakeholders, indicators, and sub-indicators. This challenge is further compounded by the agri-food sector's limited emphasis on social sustainability [30]. Examining the social aspect of the rice sector is crucial for understanding the multifunctionality of agriculture, which must not only meet global food demands but also contribute to economic and societal growth. This involves expanding the focus beyond agriculture to encompass the enhancement of rice fields, local communities, and their traditions—an interconnected system considered a heritage of the environment, culture, and mankind. Therefore, an attempt was made to provide an initial comprehensive assessment of the potential hazards associated with rice farming in various countries among the 12 mentioned in the literature (Bangladesh, Brazil, China, India, Iran, Italy, Japan, Malaysia, Senegal, Spain, Sri Lanka, and Thailand). In this effort, the Product Social Impact Life Cycle Analysis (PSILCA) standards were considered, offering a comprehensive database with 87 indicators to evaluate social aspects across various stakeholder groups [31].

The PSILCA standards, grounded in the UNEP framework, were utilized in the study formulation. Implications were categorized into social risk levels for each indicator, ranging from no danger to very high risk. The selection process considered nine criteria: Child labor, forced labor, Fair Wages, Working Hours, Workers' Rights, Discrimination, Health and Safety, Access to Material Resources, and Migration. Two stakeholder types, the local community, and workers, were deliberately included. The breakdown of the nine categories into twelve subcategories, each with its own signal, is displayed. The choice of indicators considered data availability in the database and the significance of connections between the rice sector and other impact categories.

Due to the absence of a reference standard for S-LCA and reliance on only two databases, PSILCA and SHDB, precautions are necessary. PSILCA generally provides data at sector, national, or aggregate levels. Generalizations are crucial, as some statistics, such as "Child labor," were typically available based on macro-geographic areas rather than specific countries. Risks were assessed by considering the probability that rice production would conform to observed behavioral patterns in the industry. The lack of social effect data at the product level hinders the final assignment of social consequences, leading to the consideration of risks.

While precise predictions about a specific product's impact on society are challenging, having knowledge about the probability of a product being associated with an externality is valuable for policy-making. The analytical use of the risk concept facilitates the incorporation of hazards as explanatory factors in policy analysis, allowing for adjustments in behavior in response to perceived risks rather than actual occurrences [32].

The risks identified through a social impact assessment are potential rather than certain, acknowledging that they may or may not occur, as explicitly stated in the UNEP guidelines. It's important to note that not all countries have access to data for all indicators, leading to variations in data quality. A comprehensive analysis considered several indicators for each country, categorizing key inputs for rice cultivation into macro-areas where possible.

Specifically, "Agriculture" includes livestock and animal husbandry, involving the use of seeds and organic fertilizers. "Industry" refers to manufacturing processes, including the use of chemical fertilizers, pesticides, and plastics. "Energy sources and abiotic resources" cover mining, quarrying, and the provision of petrol, electricity, and water, involving diesel, electricity, and water use. The "Hours of work per employee" indicator disaggregates data more comprehensively for energy sources and abiotic resources, classifying items like electricity and diesel under specific subcategories. The category "International migrant workers in the sector" includes two broader categories: agriculture and industry. Data averaging across different sectors was occasionally performed, but individual sector analysis was chosen in certain cases due to the potential for overestimation or underestimation, considering their distinct nature.

The database used five risk categories—very low risk, low risk, medium risk, high risk, and very high risk—to normalize results for each indicator at the local level, following PSILCA guidelines. For the "Number of children in employment" indicator, risk levels were defined as follows: $0 < y < 2.5\%$ (very low risk), $2.5\%\ y < 5\%$ (low risk), $5\%\ y < 10\%$ (medium risk), $10\%\ y < 20\%$ (high risk), and $20\%\ y$ (very high risk), with an indication of no data available [33]. As a result, if a value falls within the 3% range, it is categorized as low risk, and this criterion applies consistently to every indicator and country. Subsequently, each risk level was assigned a numerical value ranging from 1 to 5. Specifically, the numerical values assigned to different risk levels are as follows: 1 for extremely low risk, 2 for moderate risk, 3 for medium risk, 4 for high risk, and 5 for very high risk. The ultimate results of the analysis were compared, visually presented, and assigned a numerical score.

Participants: Staff Members:

The primary impact category investigated was "Child labor," evaluated based on the percentage of children aged 5 to 17 engaged in that specific industry [34]. The inclusion of children in agricultural labor frequently involves performing strenuous and hazardous tasks, resulting in a notable occurrence of both fatal and non-fatal accidents, as well as occupational diseases. Children are often required to operate dangerous machinery, handle toxic chemicals, and use explosives in precarious situations, exposing themselves to significant risks. In the most severe instances, they may even face the prospect of experiencing catastrophic amputations [35].

As per the S-LCA findings, Senegal and India both received a score of 5/5, signifying a very high-risk level. This indicates that rice cultivation in these countries could entail significant dangers. Japan, China, and Bangladesh were assigned a rating of 3/5, indicating a medium level of risk. Conversely, the risk in other nations was minimal or non-existent. Within this category, evaluations of "forced labor" quantify both the number of goods produced through forced work (70) within the sector and the occurrence of forced labor (71) per 1000 individuals in the country.

Expanding the scope of the outcome by considering both the count of individuals involved and the count of objects produced aims to strengthen the hypothesis regarding forced labor. In the first scenario, this indicator gauges the likelihood of forced labor in a particular country. S-LCA results indicate that Brazil and India have the highest risk, with a rating of 5 out of 5 for Brazil and 3 out of 5 for India. Significantly, Brazil employed coerced work for cultivating both cattle and rice. Moreover, concerning rice production, there is a very probable correlation between the use of forced labor and the sourcing of manure for organic farming [36].

In India, coerced labor is often employed for rice harvesting, typically resulting from farmers being indebted to land, mills, and other property owners. To settle these obligations, farmers may subject themselves to involuntary servitude. Iran and Thailand face significant challenges related to forced labor, with Iran posing a very high danger and Thailand a medium risk. The analysis considered the frequency of forced labor instances per 1000 people.

In Iran, forced labor primarily involves incarcerated individuals who have either committed crimes or are unable to meet financial responsibilities due to adverse economic conditions. These prisoners engage in labor in return for compensation, the opportunity to secure release by paying a sum of money, or the possibility of parole. Therefore, there is a moderate to high likelihood that rice consumed in countries like Brazil, India, Iran, and Thailand, where essential worker rights are not fully respected, may have originated from these regions.

The analysis further examined the impact category "Fair wage," assessing whether the average sector wage per month is sufficient for a decent standard of living. India and Sri Lanka emerged as nations with the greatest risks of insufficient wages in the rice supply chain, especially in the agricultural sector. A higher ratio between the subsistence wage and the minimum salary suggests a greater probability of inadequate wages, contributing to poor living conditions. India and Sri Lanka faced significant risks (rated 5 out of 5) in the energy sources/abiotic resources sector. In terms of "Working time," Bangladesh exhibited the highest likelihood of incorrect working hours in rice farming compared to other supply chains, as measured by "Hours of work per employee, per week." These findings highlight potential social concerns associated with rice production, emphasizing the importance of fair wages, working conditions, and adherence to international labor standards. Addressing these issues aligns with Sustainable Development Goals related to poverty reduction, decent work, and economic growth [37].

The assessment of "Working time" indicates a moderate probability of encountering inaccurate working hours in the agricultural sector (3/5), while the likelihood of this happening in the industrial sector and in the energy, sources utilized for rice production is quite high (5/5). The evaluation is based on the foundation provided by ILO Conventions No. 1 and No. 47, with Convention No. 47 establishing the standard working week as 40 hours. In certain nations, like Bangladesh and India, working hours in manufacturing, mining, and energy generation substantially exceed the standard of 48 hours per week, suggesting that rice agriculture in these countries may lead to unpredictable working hours due to the reliance on fertilizers, pesticides, and energy sources produced in sectors with excessive working hours.

The discrimination category, assessed through the gender wage gap, indicates that Bangladesh, Senegal, and Sri Lanka are the countries most susceptible to encountering gender discrepancies due to rice cultivation. Senegal and Sri Lanka face a significant risk (5/5) of wage inequality, particularly in the agricultural and pesticide/fertilizer sectors. Addressing gender inequality in agriculture is crucial for eradicating hunger, enhancing children's health and education, and preparing for climate change, aligning with Sustainable Development Goals 5.1 and 5.5.

The "Health and safety" category is subdivided into two subcategories: "Workers affected by natural disasters" and "Fatal accidents at workplaces." Thailand, Brazil, Japan, and Italy are identified as countries where rice agriculture is most likely to result in fatal workplace accidents. The drying of rice by the side of the road in Thailand exposes farmers to significant hazards. Bangladesh, China, Sri Lanka, Iran, and India face a moderate to very high risk of workers being impacted by natural disasters during rice field operations. Climate change exacerbates these risks, potentially hindering progress toward SDGs 1.5, 3.9, 8.8, 11.5, 13.1, and 16.6.

Trade union density was considered, revealing a concerning situation where it was highly probable (4/5) or extremely probable (5/5) that workers would be prohibited from establishing unions in all countries analyzed, except China. This suggests a significant risk in the rice industries of various countries if agricultural worker groups are not directly included in national social dialogue institutions, potentially affecting the achievement of SDGs 8.8, 16.3, and 16.5. The comprehensive analysis emphasizes the need for sustainable and socially responsible practices in rice cultivation to align with global development goals.

Participants: Local Community:

The analysis of the industrial water usage category, which encompasses the production of nitrogen fertilizers, pesticides, and other inputs used in rice production, indicates that, except for Malaysia, Italy, and China, which had a moderate risk, industrial production has a very low or low potential threat for all the countries examined. The potential impact of industrial water usage on water resources is particularly relevant when considering the production of agricultural inputs like fertilizers and pesticides. China's excessive usage of fertilizers, leading to nutrient levels significantly higher than the global average, raises concerns about environmental sustainability and the need for more responsible agricultural practices. The analysis also highlights the importance of understanding the impact of industrial water usage on water stress levels, especially in regions where continuous water pumping is necessary for rice cultivation.

The consideration of "International migrant workers in the sector" as an impact category reveals challenges in obtaining comprehensive and reliable data, undermining the reliability of this category. However, from the limited evidence provided, Italy and Spain appear to be the most susceptible countries, with notable likelihoods of bias and conflict emerging in the agricultural and industrial production sectors, particularly in rice cultivation and fertilizer production. The migration of people from developing countries to more developed countries, as observed in Spain and Italy, can be associated with unfavorable economic conditions and may counterbalance a low to exceedingly low likelihood of violence and discrimination in certain countries. This aspect emphasizes the complex social and economic dynamics involved in the agricultural and industrial sectors, requiring careful consideration for sustainable and socially responsible practices [38].

Key Discoveries:

The comprehensive analysis reveals that India consistently exhibits the highest level of medium-high social risks associated with working conditions, particularly in the context of rice agriculture, which poses the greatest social hazards. Following India, Sri Lanka, Thailand, and Bangladesh are identified as countries with notable social risks related to rice production. India's significant role in the global rice trade, being the foremost rice exporter and holding the second position in terms of global rice production, highlights the potential widespread impact of social issues associated with rice agriculture in the country. With a market share above 40%, India's rice varieties, including basmati rice and others, are distributed to more than 150 countries worldwide [39].

The analysis underscores the importance of acknowledging the potential social consequences associated with rice production, including child labor, forced labor, and other issues. The distortion in the analysis due to the significant absence of data emphasizes the need for more comprehensive and accurate information to assess the true social impact of rice agriculture globally. Furthermore, the study suggests that stakeholders, politicians, and individuals can potentially modify their behavior based on their perception of risk, even before experiencing the actual risks associated with rice production. This highlights the role of awareness and information in influencing decision-making and driving positive changes in agricultural practices. The study concludes by emphasizing the imperative need for additional research into the societal impacts of rice agriculture. It serves as a valuable starting point for further investigations and discussions on promoting sustainable and socially responsible practices in the global rice industry.

Conclusions, Limitations, and Recommendations for Future Research:

The 72 studies identified in the literature have been deemed suitable for this research, providing valuable insights into the extent of Life Cycle Thinking adoption in the rice industry. These studies highlight key methodological challenges and areas that need attention in the application of LCA to rice production. The predominant use of mass units, specifically focusing on one hectare of land and one tonne of product output, was noted in most studies. However, the limited consideration of multiple functional units indicates a lack of recognition of the multi-functionality in the rice sector. The authors recommend employing various operational entities to emphasize agriculture's various roles, including environmental, social, cultural, and historical aspects, to manage resources and engage with external factors effectively.

The diversity in methodological options, including different approaches, system boundaries, and assumptions, was as expected. The cradle-to-farm-gate approach was commonly used, considering various phases, inputs, farming methods, and output variances. However, the variations in methodologies across studies make comparisons challenging. The authors suggest future research should strive for closer alignment with prior studies to enhance comparability and accuracy in assessing environmental impacts. The influence of soil and temperature attributes on environmental consequences, particularly in water and fertilizer management, was highlighted. The focus on water management by Italian writers and fertilizer management by Asian writers reflects regional priorities. The study emphasizes the need for more comprehensive LCA investigations conducted by leading rice-producing countries and suggests a research gap, especially considering the substantial environmental impacts of rice cultivation.

The limited attention to uncertainty analysis and the proposal for increased sensitivity analysis underscore its significance. The study identifies concerns around the environmental and atmospheric impacts of agricultural practices, specifically related to chemical nitrogen fertilizers. The authors recommend addressing the issue of decreasing reliance on fossil fuels in LCA assessments, even amid global energy commodity crises. There's a research gap in organic rice cultivation and the progress of organic agriculture, with few publications focusing on these topics. Most sustainability assessments in agriculture have primarily focused on the environmental dimension, with limited attention to economic and social factors. The study advocates for a comprehensive three-pillar approach to sustainable development in rice production, encompassing economic, social, and environmental considerations.

The introduction of a Social Life Cycle Analysis for the rice industry in specific nations reveals the potential for moderate to significant social problems in Bangladesh, India, Sri Lanka, and Thailand. Methodological deficiencies and uncertainties in data accuracy underscore the need for further investigation. The study's conclusions and results provide a valuable basis for additional research, emphasizing the importance of holistic assessments that consider environmental, economic, and social sustainability in a fuller Life Cycle Thinking evaluation. The authors recommend diverse functional units and a comprehensive approach to address the multi-functionality of agriculture and rice cultivation.

References:

[1] D. Tilman et al., "Forecasting agriculturally driven global environmental change," Science (80-.)., vol. 292, no. 5515, pp. 281–284, Apr. 2001, doi: 10.1126/SCIENCE.1057544.

[2] "(PDF) Evaluation of the environmental impacts of rice paddy production using life cycle assessment: case study in Bangladesh." Accessed: Feb. 16, 2024. [Online]. Available: https://www.researchgate.net/publication/319202619_Evaluation_of_the_environmental_impacts_of_rice_paddy_production_using_life_cycle_assessment_case_study_in_Bangladesh

[3] M. A. J. Huijbregts et al., "ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level," Int. J. Life Cycle Assess., vol. 22, no. 2, pp. 138–147, Feb. 2017, doi: 10.1007/S11367-016-1246-Y.

[4] B. Mattsson and E. Wallén, "Environmental Life Cycle Assessment (LCA) of organic potatoes," Acta Hortic., vol. 619, pp. 427–435, 2003, doi: 10.17660/ACTAHORTIC.2003.619.51.

[5] B. Notarnicola, K. Hayashi, M. A. Curran, and D. Huisingh, "Progress in working towards a more sustainable agri-food industry," J. Clean. Prod., vol. 28, pp. 1–8, Jun. 2012, doi: 10.1016/J.JCLEPRO.2012.02.007.

[6] X. Xu et al., "Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods," Nat. Food 2021 29, vol. 2, no. 9, pp. 724–732, Sep. 2021, doi: 10.1038/s43016-021-00358-x.

[7] S. Kirschke et al., "Three decades of global methane sources and sinks," Nat. Geosci. 2013 610, vol. 6, no. 10, pp. 813–823, Sep. 2013, doi: 10.1038/ngeo1955.

[8] T. Nemecek, N. Jungbluth, L. M. i Canals, and R. Schenck, "Environmental impacts of food consumption and nutrition: where are we and what is next?," Int. J. Life Cycle Assess., vol. 21, no. 5, pp. 607–620, May 2016, doi: 10.1007/S11367-016-1071-3.

[9] G. Singh, M. K. Gupta, S. Chaurasiya, V. S. Sharma, and D. Y. Pimenov, "Rice straw burning: a review on its global prevalence and the sustainable alternatives for its effective mitigation," Environ. Sci. Pollut. Res., vol. 28, no. 25, pp. 32125–32155, Jul. 2021, doi: 10.1007/S11356-021-14163-3/METRICS.

[10] S. Zingale, P. Guarnaccia, A. Matarazzo, G. Lagioia, and C. Ingrao, "A systematic literature

review of life cycle assessments in the durum wheat sector," Sci. Total Environ., vol. 844, p. 157230, Oct. 2022, doi: 10.1016/J.SCITOTENV.2022.157230.

[11] P. Roy, K. Tokuyasu, T. Orikasa, N. Nakamura, and T. Shiina, "A Review of Life Cycle Assessment (LCA) of Bioethanol from Lignocellulosic Biomass," Japan Agric. Res. Q. JARQ, vol. 46, no. 1, pp. 41–57, Jan. 2012, doi: 10.6090/JARQ.46.41.

[12] B. Khoshnevisan et al., "Evaluation of traditional and consolidated rice farms in Guilan Province, Iran, using life cycle assessment and fuzzy modeling," Sci. Total Environ., vol. 481, no. 1, pp. 242–251, May 2014, doi: 10.1016/J.SCITOTENV.2014.02.052.

[13] S. Dastan, B. Ghareyazie, J. A. Teixeira da Silva, and S. H. Pishgar-Komleh, "Assessment of the life cycle of genetically modified and non-genetically modified rice cultivars," Arab. J. Geosci., vol. 13, no. 10, pp. 1–14, May 2020, doi: 10.1007/S12517-020-05386-8/METRICS.

[14] E. Houshyar, B. Chen, and G. Q. Chen, "Environmental impacts of rice production analyzed via social capital development: An Iranian case study with a life cycle assessment/data envelopment analysis approach," Ecol. Indic., vol. 105, pp. 675–687, Oct. 2019, doi: 10.1016/J.ECOLIND.2018.07.040.

[15] A. M. Shew, A. Durand-Morat, B. Putman, L. L. Nalley, and A. Ghosh, "Rice intensification in Bangladesh improves economic and environmental welfare," Environ. Sci. Policy, vol. 95, pp. 46–57, May 2019, doi: 10.1016/J.ENVSCI.2019.02.004.

[16] K. Masuda, "Eco-Efficiency Assessment of Intensive Rice Production in Japan: Joint Application of Life Cycle Assessment and Data Envelopment Analysis," Sustain. 2019, Vol. 11, Page 5368, vol. 11, no. 19, p. 5368, Sep. 2019, doi: 10.3390/SU11195368.

[17] M. H. Abdul Rahman et al., "Life cycle assessment in conventional rice farming system: Estimation of greenhouse gas emissions using cradle-to-gate approach," J. Clean. Prod., vol. 212, pp. 1526–1535, Mar. 2019, doi: 10.1016/J.JCLEPRO.2018.12.062.

[18] A. Ahmad, M. Zoli, C. Latella, and J. Bacenetti, "Rice cultivation and processing: Highlights from a life cycle thinking perspective," Sci. Total Environ., vol. 871, May 2023, doi: 10.1016/J.SCITOTENV.2023.162079.

[19] X. He, Y. Qiao, L. Liang, M. T. Knudsen, and F. Martin, "Environmental life cycle assessment of long-term organic rice production in subtropical China," J. Clean. Prod., vol. 176, pp. 880–888, Mar. 2018, doi: 10.1016/J.JCLEPRO.2017.12.045.

[20] S. N. Harun, M. M. Hanafiah, and N. I. H. A. Aziz, "An LCA-Based Environmental Performance of Rice Production for Developing a Sustainable Agri-Food System in Malaysia," Environ. Manage., vol. 67, no. 1, pp. 146–161, Jan. 2021, doi: 10.1007/S00267-020-01365-7/METRICS.

[21] L. Yu et al., "Life cycle assessment of liquid digestate application strategies for rice agri-food chain in 'Zero-waste City,'" Biomass Convers. Biorefinery, vol. 12, no. 10, pp. 4389–4401, Mar. 2022, doi: 10.1007/S13399-022-02542-W/METRICS.

[22] C. Gouel and H. Guimbard, "Nutrition Transition and the Structure of Global Food Demand," Am. J. Agric. Econ., vol. 101, no. 2, pp. 383–403, Mar. 2019, doi: 10.1093/AJAE/AAY030.

[23] A. Gani, "Greenhouse gas emissions from the production of cereals and livestock across high-, middle- and low-income countries," Renew. Agric. Food Syst., vol. 37, no. 1, pp. 36–48, 2022, doi: 10.1017/S1742170521000272.

[24] J. Su et al., "Expression of barley SUSIBA2 transcription factor yields high-starch low-methane rice," Nat. 2015 5237562, vol. 523, no. 7562, pp. 602–606, Jul. 2015, doi: 10.1038/nature14673.

[25] N. Ukrainczyk and E. A. B. Koenders, "Sustainability aspects in mass concrete," RILEM State-of-the-Art Reports, vol. 27, pp. 357–409, 2019, doi: 10.1007/978-3-319-76617-1_10/COVER.

[26] I. Quispe, R. Navia, and R. Kahhat, "Energy potential from rice husk through direct combustion and fast pyrolysis: A review," Waste Manag., vol. 59, pp. 200–210, Jan. 2017, doi: 10.1016/J.WASMAN.2016.10.001.

[27] X. Shen, L. Zhang, and J. Zhang, "Ratoon rice production in central China: Environmental sustainability and food production," Sci. Total Environ., vol. 764, p. 142850, Apr. 2021, doi: 10.1016/J.SCITOTENV.2020.142850.

[28] E. Habibi, Y. Niknejad, H. Fallah, S. Dastan, and D. B. Tari, "Life cycle assessment of rice production systems in different paddy field size levels in north of Iran," Environ. Monit. Assess., vol. 191, no. 4, pp. 1–23, Apr. 2019, doi: 10.1007/S10661-019-7344-0/METRICS.

[29] M. Rezaei, F. Soheilifard, and A. Keshvari, "Impact of agrochemical emission models on the environmental assessment of paddy rice production using life cycle assessment approach," Energy Sources, Part A Recover. Util. Environ. Eff., Jan. 2021, doi: 10.1080/15567036.2020.1864066.

[30] A. Abolhasani, B. Samali, and F. Aslani, "Rice Husk Ash Incorporation in Calcium Aluminate Cement Concrete: Life Cycle Assessment, Hydration and Strength Development," Sustain. 2022, Vol. 14, Page 1012, vol. 14, no. 2, p. 1012, Jan. 2022, doi: 10.3390/SU14021012.

[31] A. N. Jimmy, N. A. Khan, M. N. Hossain, and M. Sujauddin, "Evaluation of the environmental impacts of rice paddy production using life cycle assessment: case study in Bangladesh," Model. Earth Syst. Environ., vol. 3, no. 4, pp. 1691–1705, Dec. 2017, doi: 10.1007/S40808-017-0368-Y/METRICS.

[32] S. Yodkhum, S. Sampattagul, and S. H. Gheewala, "Energy and environmental impact analysis of rice cultivation and straw management in northern Thailand," Environ. Sci. Pollut. Res., vol. 25, no. 18, pp. 17654–17664, Jun. 2018, doi: 10.1007/S11356-018-1961-Y/METRICS.

[33] N. Arunrat, C. Wang, and N. Pumijumnong, "Reprint of Alternative cropping systems for greenhouse gases mitigation in rice field: a case study in Phichit province of Thailand," J. Clean. Prod., vol. 134, pp. 547–562, Oct. 2016, doi: 10.1016/J.JCLEPRO.2016.08.015.

[34] J. Bacenetti, A. Fusi, M. Negri, S. Bocchi, and M. Fiala, "Organic production systems: Sustainability assessment of rice in Italy," Agric. Ecosyst. Environ., vol. 225, pp. 33–44, Jun. 2016, doi: 10.1016/J.AGEE.2016.03.046.

[35] R. Mungkung, P. Pengthamkeerati, R. Chaichana, S. Watcharothai, K. Kitpakornsanti, and S. Tapananont, "Life Cycle Assessment of Thai organic Hom Mali rice to evaluate the climate change, water use and biodiversity impacts," J. Clean. Prod., vol. 211, pp. 687–694, Feb. 2019, doi: 10.1016/J.JCLEPRO.2018.11.197.

[36] T. Hishinuma, S. Ono, and A. Ikeguchi, "Scenario Analysis of Environmental Impact of Paddy Rice Farming Systems Utilizing Different Fertilizer Materials," Sustain. Prod. Life Cycle Eng. Manag., pp. 415–427, 2021, doi: 10.1007/978-981-15-6775-9_27/COVER.

[37] Y. Chen, C. Liu, J. Chen, N. Hu, and L. Zhu, "Evaluation on environmental consequences and sustainability of three rice-based rotation systems in Quanjiao, China by an integrated analysis of life cycle, emergy and economic assessment," J. Clean. Prod., vol. 310, p. 127493, Aug. 2021, doi: 10.1016/J.JCLEPRO.2021.127493.

[38] S. Yodkhum, S. H. Gheewala, and S. Sampattagul, "Life cycle GHG evaluation of organic rice production in northern Thailand," J. Environ. Manage., vol. 196, pp. 217–223, Jul. 2017, doi: 10.1016/j.jenvman.2017.03.004.

[39] "View of Position of Pakistani Basmati Rice in International Markets (A Comparative Analysis)." Accessed: Feb. 22, 2024. [Online]. Available: https://journal.50sea.com/index.php/IJASD/article/view/430/518